Effect of Replacing Alfalfa Silage with High Moisture Corn on Nutrient Utilization and Milk Production[1]

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ABSTRACT

Twenty-four multiparous lactating Holstein cows were blocked by days in milk and assigned to treatment sequences in a replicated 4 × 4 Latin square with 21-d periods. The four diets, formulated from alfalfa silage plus a concentrate mix based on ground high moisture ear corn, contained [dry matter (DM) basis]: 1) 20% concentrate, 80% alfalfa silage (24% nonfiber carbohydrates; NFC), 2) 35% concentrate, 65% alfalfa silage (30% NFC), 3) 50% concentrate, 50% alfalfa silage (37% NFC), or 4) 65% concentrate, 35% alfalfa silage (43% NFC). Soybean meal and urea were added to make diets isonitrogenous with equal nonprotein N (43% of total N). Intake of DM and milk yield indicated that adaptation was complete within 7 d of changing the diets within the Latin square. There were linear increases in apparent digestibility of DM and organic matter, and a linear decrease in neutral detergent fiber (NDF) digestibility with increasing dietary NFC. Solutions of significant quadratic equations yielded estimated maxima for intake of DM, organic matter, digestible organic matter, and NDF at, respectively, 37, 38, 43, and 27% dietary NFC. There were linear increases in yields of milk, protein, lactose, and solids not fat with increasing dietary NFC. Feed efficiency (milk/DM intake) yielded a quadratic response with a minimum at 27% dietary NFC. Maxima for milk fat content, fat yield, and fat-corrected milk yield were estimated to occur at, respectively, 30, 34 and 38% dietary NFC. In this short-term trial, maximal DM intake and fat-corrected milk yield indicated that the optimum concentrate for cows fed high moisture ear corn plus alfalfa silage as the only forage was equivalent to 37 to 38% dietary NFC; however, yields of milk, protein and solids not fat were still increasing at 65% dietary concentrate (43% NFC).
(**Key words:** alfalfa silage, nonfiber carbohydrate, high moisture corn)

Abbreviation key: AS = alfalfa silage, **DOM** = digestible organic matter, **HMEC** = ground high moisture ear corn, **MUN** = milk urea N, **NFC** = nonfiber carbohydrates, **SBM** = solvent extracted soybean meal.

INTRODUCTION

To achieve high milk yields, dairy cows must be fed sufficient energy and protein. Alfalfa silage (**AS**) is one of the most common forages fed to dairy cows in the United States; however, during ensiling, more than half of the CP in AS usually is degraded to NPN (14). Microbial utilization of the NPN in AS is stimulated by adding fermentable energy such as starch to the diet (33). Because of its granular structure, the starch in corn is not extensively degraded in the rumen. Processing corn improves its digestibility in the rumen and intestine. For example, grinding high-moisture corn just prior to feeding improved its utilization by lactating cows (11, 35). Nocek and Russell (23) suggested that rations for high producing cows contain 78% total carbohydrate, 53% ruminally available carbohydrate, and 16% CP, 66% of which is ruminally available protein. Microbial protein production was reported to be maximal when rations contained 10 to 13% RDP and 56% nonfiber carbohydrates (**NFC**) (13).

Dry matter intake is an important criterion when formulating diets for high-yielding dairy cows (21). The optimum NDF to include in the diet varies with milk production and the type of forage fed (17). Mertens (16) reported that lactation performance was constrained by energy supply when dietary NDF intake was greater than 1.2% of BW for diets with 75% of the total NDF supplied by forage. General guidelines for providing

Received March 26, 1999.
Accepted August 9, 1999.
[1]Mention of any trademark or proprietary product in this paper does not constitute a guarantee or warranty of the product by the USDA or the Agricultural Research Service and does not imply its approval to the exclusion of other products that also may be suitable.
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adequate effective fiber in the diet and maintaining optimal DMI include total NDF between 25 to 35%, maintaining a minimum of 18% forage NDF, and feeding 33 to 40% NFC (34).

The objective of this experiment was to determine how much concentrate can be fed in diets based on AS to maximize lactation performance and utilization of the NPN in AS.

MATERIALS AND METHODS

Twenty-four multiparous, lactating Holstein cows (8 fitted with ruminal cannulas) [BW, 610 ± 26 kg; milk yield, 40 ± 7 kg/d; parity, 3.0 ± 1.1; and DIM, 54 ± 15 (mean ± SD)], were blocked by DIM (two blocks of ruminally cannulated cows) and randomly assigned to dietary sequences within six 4 × 4 Latin squares with 3-wk periods (total 12 wk). The six 4 × 4 Latin squares were balanced for carry over effects (i.e., each treatment followed every other treatment one time within each square). Data from ruminal sampling are reported in a companion paper (32). Treatments were four diets, fed as TMR, containing (DM basis) 80, 65, 50, or 35% AS as the sole forage plus 20, 35, 50, or 65% concentrate (Table 1). High-moisture ear corn (**HMEC**) that was ground through a 1-cm screen using a hammer mill (Meter/Mill; Clay Equipment Corp., Cedar Falls, IA) after removal from the silo was the principal component of the concentrate. Diets were held isonitrogenous by adding solvent-extracted soybean meal (**SBM**) and urea as AS was decreased; urea was added to maintain a constant proportion of NPN (43% of total N). Potassium and magnesium sulfate, a source of inorganic S, was added to maintain the N:S ratio at about 11 across all diets. All cows were injected with bST (500 mg/d of Posilac®; Monsanto, St. Louis, MO) beginning on d 8 of period 1 of the trial and continuing at 14-d intervals throughout. Therefore, cows received bST once during periods 1 and 3 (on d 8) and twice during periods 2 and 4 (on d 1 and d 15). Because the design was a balanced 4 × 4 Latin square, an equal number of observations were made for each dietary treatment during periods in which bST was injected on d 8 and on d 1 and 15. Cows were housed in tie stalls and had free access to water throughout the trial. Cows were offered TMR once daily at 1100 h; orts were collected and recorded once daily. The feeding rate was adjusted daily to yield orts of about 5% of intake. Weekly composites of AS, HMEC, TMR, and orts were prepared from daily samples of about 0.5 kg that were stored at –20°C. Weekly samples also were taken of SBM and urea and stored at 21 to 24°C. Dietary contents of AS and HMEC (as-fed basis) were adjusted weekly based on DM determined at 60°C (48 h). Mean DM contents of TMR at 20, 35, 50, and 65% concentrate were 40.6, 44.1, 48.3, and 53.5%, respectively. Body weights were measured on 2 consecutive d at the start and end of each period to compute BW change.

Cows were milked twice daily and individual milk yields were recorded at each milking. Milk samples were collected at two consecutive milkings (p.m. and a.m.) on d 12 and d 19 of each period during the trial and each sample was analyzed for fat, protein, lactose, SNF, and SCC by infrared analysis (AgSource, Menomonie, WI). Milk was deproteinized (11) and analyzed for milk urea N (**MUN**) by colorimetric assay (31). Concentrations and yields of fat, protein, lactose, SNF, 3.5% FCM (27), and MUN were computed as the weighted means from a.m. and p.m. milk yields on each test day of each period. Feed efficiency was computed for each cow by dividing mean milk yield by mean DMI over wk 2 and 3 of each period. Two fecal grab samples were collected from each cow during each period—at 1700 h of d 14 and 0600 h of d 19 (2). After drying (60°C; 72 h) and grinding through a 1-mm screen (Wiley mill; Arthur H. Thomas, Philadelphia, PA), a single composite fecal sample was made for each cow per period.

Proportions of dietary DM from each ingredient were determined by drying weekly composites at 60°C (48 h) for AS and HMEC and at 105°C (1) for urea and SBM. Weekly samples of TMR and orts also were dried at 60°C (48 h); DMI was computed on this basis. Previously, orts were found not to differ in composition from TMR when all of the dietary forage was from silage (2). After drying, ingredients and TMR were ground through a 1-mm screen. Dried, ground samples from wk 2 and 3 of each period were analyzed for ash (1), total N, starch (11), and NDF, neutral detergent insoluble CP, ADF, and acid detergent lignin (12, 25). Analyses of NDF and neutral detergent insoluble CP were made with Na_2SO_3 and heat stable α-amylase (D. R. Mertens, 1994, personal communication). Total N and N fractions were measured by combustion (Leco 2000; Leco Instruments, Inc., St. Joseph, MI). Fat in TMR was assayed (Commercial Testing Laboratory, Colfax, WI). Dietary carbohydrate fractions were computed from TMR data with NRC (22) equations, except that available fiber (fraction CB2) was calculated by subtracting both unavailable fiber (fraction CC) and neutral detergent insoluble CP from NDF. Fecal composites were analyzed as described for CP, OM, NDF, and ADF. Both fecal composites and TMR samples were analyzed for indigestible ADF (ADF remaining after 144 h of in vitro ruminal incubations; 8). Apparent digestibilities were computed with these concentrations of indigestible ADF (6). Frozen samples of AS were thawed and water extracts were prepared (19), deproteinized (19), and analyzed for total AA and NH_3 (4) and for NPN (19).

Statistical Analysis

Week 1 of each period served as adaptation, and data were discarded from this time; mean DMI and yield of milk and each milk component were computed for each cow for wk 2 through 3 of each period. Intake and yield data were analyzed as a 4×4 Latin square, replicated six times by the general linear models procedure of SAS (26). The model included square, cow-within-square, period, and diet, plus diet-by-square and diet-by-period interactions. Effects from the pattern of bST injection will be blended with the period effect. No diet-by-period interaction was significant ($P \geq 0.16$) for any variable, indicating that the pattern of bST injection will not confound interpretation of the effects of diet in this trial. When significant ($P \leq 0.05$) effects due to diet were detected, mean separation was conducted by Tukey's method ($P = 0.05$). Regressions of response variables on dietary NFC were obtained by using a model that included square, cow-within-square, period, and linear and quadratic effects of dietary NFC level. Dietary NFC levels (percentage of DM) at maximum (or, in one case, minimum) responses were determined by taking the first derivative of quadratic equations with significant ($P \leq 0.05$) regression coefficients. To test whether the length of time allowed for adaptation was adequate, daily milk yield and DMI were analyzed with the mixed procedure of SAS (26) using a repeated measures model that included square, period, diet, day, diet-by-day interaction, and random effects for cow within square and cow within square by (period by diet).

RESULTS AND DISCUSSION

Alfalfa silage fed in this trial averaged 36.6% DM (60°C); 20.7% CP and 47.6% NDF (DM basis); 11% ammonia-N, 31% total AA-N and 53% NPN (% of total N); and 5.1 pH. The HMEC averaged 69.3% DM (60°C), 9.7% CP, and 10.4% NDF (DM basis). Composition of HMEC was typical of that fed to lactating cows (11). The pH, NPN, and CP contents of the AS also were similar to that of AS found in commercial tower silos; however, NDF content was higher and more typical of AS from bunker silos (14). Thus, all diets, including that with 65% concentrate, contained more than the minimum 25% total NDF and 18% forage NDF (Table 1) recommended by Varga (34). Although diets were similar in total carbohydrate (Table 1), each replacement of 15 percentage units of DM from AS with the concentrate mix of HMEC, SBM, and urea decreased total NDF and available fiber (fraction CB2) by, respectively, an average 5.1 and 2.0 percentage units and increased NE_L [computed from NRC (21) tables] by an average 0.09 Mcal/kg. Sugar content, computed from the analyzed carbohydrate fractions, declined as AS was diluted by HMEC but NFC increased by 6.1 percentage units with each increment of added concentrate (Table 1).

The mean weekly patterns of DMI and milk yield supported the hypothesis that 7 d was adequate for adaptation to diet changes in this trial. Statistical inferences on effect of diet on DMI (expressed per unit of BW or as amount per day) and milk yield were the same for both wk 2 and 3 (Table 2). This indicated that using mean data from wk 2 and 3 would be appropriate for assessing the effects of dietary concentrate in the present experiment. Storry and Sutton (29) reported only minor fluctuations in the proportions of ruminal VFA 1 wk after changing from a low-roughage to high-roughage diet. However, despite detection of dietary treatment effects by wk 2 of the 3-wk period, use of relatively short periods could mute possible adverse influences of high concentrate feeding. For example, milk fat yield may not reach its nadir within 3 wk because of the cow's ability to mobilize body fat over an extended time (15); fat mobilization would decline after body fat stores became exhausted. Other negative effects of high concentrate feeding on ruminal function also may have been exacerbated with time.

Generally, there were linear increases in apparent nutrient digestibility (determined by using indigestible ADF as internal marker) with decreasing AS and increasing concentrate in the diet (Table 3). Improvement of DM and OM digestibility may be attributed to reduced content of less digestible NDF and increased content of more digestible starch and NFC in the diet. The linear decline in NDF digestibility with increasing dietary concentrate is in agreement with many literature reports; increased intake of the NFC from HMEC and SBM likely would reduce ruminal pH and, thus, depress NDF digestibility (11). Digestibility of ADF had a significant quadratic response to increasing concentrate; maximal ADF digestibility was estimated to occur at 29% dietary NFC (Table 4). Digestibility of CP increased linearly with concentrate level. Generally, apparent CP digestibility is augmented by dietary CP content due to dilution of endogenous N secretions (28); however, CP level was similar in all four diets (Table 1). Replacement of CP from AS with CP from SBM and urea, both of which have high true digestibilities, plus reduction of fiber-bound CP when AS was replaced in the diet (Table 1) likely contributed to the linear increase in apparent CP digestibility. Determining indigestible ADF as the residue from 6-d in vitro incubations may have resulted in an underestimation of digestibility. Compared with using the external marker, Yb, apparent digestibilities were 6 (DM and OM), 9 (NDF and ADF), and 7 (CP) percentage units lower when estimated using (6-d in vitro) indigestible ADF

Table 1. Composition of diets.

Item	Dietary concentrate (% of DM)			
	20	35	50	65
	(% of DM)			
Alfalfa silage	79.64	65.26	50.30	35.30
High moisture ear corn[1]	18.81	30.87	43.63	56.44
Solvent soybean meal	. . .	1.87	3.54	5.22
Urea[2]	. . .	0.41	0.84	1.26
Dicalcium phosphate	0.62	0.60	0.61	0.61
Sodium bicarbonate	0.52	0.50	0.50	0.50
Potassium and magnesium sulfate[3]	. . .	0.09	0.18	0.27
Salt	0.31	0.30	0.30	0.30
Mineral and vitamin premix[4]	0.10	0.10	0.10	0.10
Chemical composition				
CP	19.5	20.1	19.9	19.7
Fat	3.6	4.0	3.7	3.3
NE_L[5] (Mcal/kg)	1.40	1.48	1.57	1.66
Starch	12.3	20.7	29.5	38.3
NDF	42.9	38.2	32.6	27.7
Neutral detergent insoluble N (% of total N)	10.5	8.9	7.3	6.0
ADF	33.5	29.5	23.9	18.9
Acid detergent lignin	6.5	5.4	4.2	3.0
Indigestible ADF	19.9	16.8	13.1	9.7
Ash	11.5	10.2	9.1	7.7
Carbohydrate fractions[6]				
Total carbohydrate (CHO)	65.4	65.7	67.3	69.3
Unavailable fiber (CC)	19.9	15.3	14.6	10.7
Available fiber (CB2)	21.0	21.1	16.6	15.9
Nonfiber carbohydrate (NFC)[7]	24.5	29.3	36.2	42.8
Sugars (CA)	12.3	8.7	6.7	4.5

[1]High moisture ear corn was ground with a hammer mill through a 9.5-mm screen.

[2]Urea added to maintain NPN at 43% of total N as in the 20% concentrate diet.

[3]Contained (per kilogram) 111 g of Mg, 184 g of K, and 222 g of S.

[4]Provided (per kg of diet DM): Zn, 56 mg; Mn, 46 mg; Fe, 22 mg; Cu, 12 mg; I, 0.9 mg; Co, 0.4 mg; Se, 0.3 mg; vitamin A, 6440 IU; vitamin D, 2000 IU; and vitamin E, 16 IU.

[5]Content of NE_L was calculated from estimated (17) NE_L in alfalfa (computed from NDF content) and from NRC (21) tables.

[6]Carbohydrate fractions described in (22). Nonfiber carbohydrate = total CHO − CB2 − CC.

[7]Nonfiber carbohydrate = CHO − CB2 − CC.

Table 2. Mean DMI and milk yield at the four levels of dietary concentrate by week over the course of the 3-wk periods of the Latin square.

Week	Dietary concentrate (% of DM)				Weekly mean
	20	35	50	65	
DMI (kg/d)					
1	$21.0^{b\ C}$	$23.6^{b\ B}$	$25.5^{a\ A}$	$24.6^{a\ AB}$	23.7^{b}
2	$21.8^{ab\ C}$	$25.1^{a\ B}$	$26.6^{a\ A}$	$25.4^{a\ AB}$	24.7^{a}
3	$22.4^{a\ C}$	$24.8^{ab\ B}$	$26.5^{a\ A}$	$25.1^{a\ AB}$	24.7^{a}
DMI (% of BW)					
1	$3.35^{b\ C}$	$3.76^{b\ B}$	$4.07^{a\ A}$	$3.93^{a\ AB}$	3.78^{b}
2	$3.48^{ab\ C}$	$3.99^{a\ B}$	$4.23^{a\ A}$	$4.05^{a\ AB}$	3.94^{a}
3	$3.57^{a\ C}$	$3.94^{ab\ B}$	$4.21^{a\ A}$	$4.00^{a\ AB}$	3.93^{a}
Milk yield (kg/d)					
1	$34.3^{a\ C}$	$37.2^{a\ B}$	$39.2^{a\ AB}$	$39.9^{b\ A}$	37.7
2	$31.2^{b\ D}$	$36.2^{ab\ C}$	$39.8^{a\ B}$	$43.1^{a\ A}$	37.6
3	$31.2^{b\ D}$	$35.3^{b\ C}$	$39.2^{a\ B}$	$43.1^{a\ A}$	37.2

[a,b]Within variable, means in the same column with different lowercase superscripts differ ($P < 0.05$).

[A,B,C,D]Means in the same row (excluding weekly mean) with different uppercase superscripts differ ($P < 0.05$).

Table 3. Effect of replacing dietary alfalfa silage with concentrate on apparent nutrient digestibility.[1]

Item	Dietary concentrate (% of DM)				SE	$P<$[2]	
	20	35	50	65		L	Q
	(%)						
DM	53.4[d]	57.9[c]	61.0[b]	66.3[a]	0.6	<0.001	0.443
OM	55.1[d]	59.5[c]	62.6[b]	67.6[a]	0.5	<0.001	0.603
NDF	37.4	36.7	36.3	35.0	0.7	0.016	0.693
ADF	38.1[a]	38.4[a]	37.6[a]	35.0[b]	0.7	0.104	0.032
CP	59.7[c]	63.7[b]	62.8[bc]	68.0[a]	1.0	<0.001	0.537

[a,b,c,d]Means in rows with different superscripts differ ($P < 0.05$).

[1]Apparent digestibility determined using indigestible ADF as internal marker (6).

[2]L = Linear effect, Q = quadratic effect.

as an internal marker in AS diets (6). However, both markers quantified the same significant differences in digestibility of CP (3 percentage units) and NDF and ADF (5 percentage units) that resulted from macerating alfalfa (5).

There were significant linear and quadratic effects of replacing AS with concentrate on BW change of the cows in this study (Table 5): BW gain was greatest on 35 and 50% concentrate, intermediate on 65% concentrate, and cows fed 20% concentrate lost BW. Body weight averaged 630 kg over the course of the trial. Significant linear and quadratic effects of concentrate level also were detected for intakes of DM, OM, digestible OM (**DOM**), NDF, ADF, and CP (Table 5). We anticipated

Table 4. Significant linear and quadratic regressions on dietary nonfiber carbohydrate.[1]

Variable (Y)	Equation	R^2	Maximum[2]
Apparent digestibility			
DMD (%)	Y = 37.4 + 0.670 NFC	0.848	. . .
OMD (%)	Y = 39.5 + 0.654 NFC	0.866	. . .
NDFD (%)	Y = 40.5 – 0.126 NFC	0.489	. . .
ADFD (%)	Y = 22.6 + 1.09 NFC – 0.0186 NFC^2	0.529	29.2%
CPD (%)	Y = 50.9 + 0.382 NFC	0.706	. . .
BW change and intake			
BW change (kg/d)	Y = –9.60 + 0.603 NFC – 0.00881 NFC^2	0.455	34.2%
DMI (kg/d)	Y = –13.0 + 2.16 NFC – 0.0294 NFC^2	0.736	36.7%
OM intake (kg/d)	Y = –13.2 + 1.99 NFC – 0.0264 NFC^2	0.751	37.6%
DOM intake (kg/d)	Y = –11.7 + 1.29 NFC – 0.0152 NFC^2	0.803	42.5%
NDF intake (kg/d)	Y = 2.64 + 0.519 NFC – 0.00972 NFC^2	0.814	26.7%
NDF intake (% of BW)	Y = 0.499 + 0.0779 NFC – 0.00148 NFC^2	0.821	26.3%
ADF intake (kg/d)	Y = 2.09 + 0.428 NFC – 0.00852 NFC^2	0.864	25.1%
Yield and MUN			
Milk yield (kg/d)	Y = 16.1 + 0.645 NFC	0.909	. . .
Milk yield/DMI	Y = 2.27 – 0.0643 NFC + 0.00119 NFC^2	0.766	(26.9%)[3]
FCM yield (kg/d)	Y = –29.5 + 3.71 NFC – 0.0483 NFC^2	0.863	38.4%
Fat (%)	Y = –0.226 + 0.273 NFC – 0.00451 NFC^2	0.686	30.2%
Fat yield (kg/d)	Y = –0.774 + 0.133 NFC – 0.00196 NFC^2	0.752	33.9%
Protein (%)	Y = 2.59 + 0.0111 NFC	0.769	. . .
Protein yield (kg/d)	Y = 0.657 + 0.0145 NFC	0.798	. . .
Lactose (%)	Y = 4.64 + 0.00551 NFC	0.733	. . .
Lactose yield (kg/d)	Y = 1.23 + 0.0192 NFC	0.841	. . .
SNF (%)	Y = 7.97 + 0.0173 NFC	0.742	. . .
SNF yield (kg/d)	Y = 2.09 + 0.0364 NFC	0.827	. . .
MUN (mg/dl)	Y = 26.8 – 0.159 NFC	0.823	. . .
MUN (% of total N)	Y = 5.51 – 0.0294 NFC	0.762	. . .
MUN secretion (g/d)	Y = –5.08 + 0.762 NFC – 0.0104 NFC^2	0.857	36.8%

[1]ADFD = ADF digestibility, CPD = CP digestibility, DMD = DM digestibility, DOM = digestible organic matter, MUN = milk urea N, NDFD = NDF digestibility, NFC = dietary NFC (% of DM), and OMD = organic matter digestibility.

[2]Dietary NFC content (% of DM) at maximum determined by taking first derivative of quadratic equations, where significant.

[3]The quadratic equation for milk yield/DM intake has the opposite shape and taking the first derivative identifies the dietary NFC content (26.9% of DM) at the minimum.

Table 5. Effect of replacing dietary alfalfa silage with concentrate on BW change and nutrient intake.[1]

	Dietary concentrate (% of DM)					$P<$	
Item	20	35	50	65	SE	L	Q
BW Change, kg/d	-0.17^{b}	0.63^{a}	0.58^{a}	0.11^{ab}	0.14	<0.001	<0.001
DMI, kg/d	22.1^{b}	25.2^{a}	26.4^{a}	25.6^{a}	0.5	<0.001	<0.001
DMI, % of BW	3.52^{b}	4.00^{a}	4.19^{a}	4.07^{a}	0.08	<0.001	<0.001
OM intake, kg/d	19.6^{b}	22.7^{a}	23.9^{a}	23.6^{a}	0.4	<0.001	<0.001
DOM intake, kg/d	10.8^{c}	13.5^{b}	15.0^{a}	15.9^{a}	0.3	<0.001	0.004
NDF intake, kg/d	9.47^{a}	9.64^{a}	8.59^{b}	7.09^{c}	0.16	0.002	<0.001
NDF intake, % of BW	1.51^{a}	1.53^{a}	1.37^{b}	1.13^{c}	0.03	0.002	<0.001
ADF intake, kg/d	7.40^{a}	7.45^{a}	6.30^{b}	4.83^{c}	0.12	0.001	<0.001
CP intake, kg/d	4.29^{b}	5.08^{a}	5.24^{a}	5.03^{a}	0.09	<0.001	<0.001

[a,b,c]Means in rows with different superscripts differ ($P < 0.05$).

[1]DOM = Digestible organic matter, L = linear effect, Q = quadratic effect.

quadratic responses in this trial, including declines in feed intake at the highest AS replacement, due to adverse effects of high concentrate feeding on ruminal fermentation (10, 24). Maxima for BW change and intakes of DM, OM, and DOM were determined to occur at NFC concentrations ranging from 34 to 43% of dietary DM (Table 4). Intake of DM ranged from 4.0 to 4.2% of BW for cows fed diets containing 35 to 65% concentrate and was similar to the value of 4% of BW cited by NRC (21) for cows weighing 600 kg and producing 40 kg/d of FCM. As expected, maxima for NDF and ADF intake were determined to occur at higher AS, corresponding to 25 to 27% dietary NFC (Table 4). Intake of NDF was unusually high and, except at the very highest level of concentrate, exceeded 1.2% of BW (16) and reached 1.5% of BW on the two diets with highest amount of AS. Maximum intake of DOM was estimated to occur at 43% NFC, which approximated the NFC content at the highest level of dietary concentrate. In this experiment, DMI may have been limited, and animal performance constrained, at 65 and 80% AS by rumen fill of undigested feed residues (16) and intake would be expected to be augmented by increased OM digestibility (7). Because of similar CP content among diets (Table 1), CP intake paralleled DMI (Table 5).

Data on milk yield and composition are in Table 6. Milk yield increased linearly ($P < 0.01$) with the increased dietary concentrate (Figure 1). This may be attributed to increased DOM intake, which should approximate TDN intake (21), with increased dietary concentrate (Table 5). Feed efficiency (milk/DMI) followed a response that had a different shape from the other quadratic curves: taking the first derivative identified a minimum for milk/DMI at 27% NFC in the diet (Table 4). However, yield of 3.5% FCM followed a quadratic response (Figure 1); maximum FCM was estimated to occur at 38% dietary NFC (Table 4). Milk fat content was unchanged from 20 to 50% concentrate but was depressed about 0.6 percentage unit at 65% dietary concentrate (Table 6). This classic pattern of depressed milk fat content with elevated NFC intake resulted in a quadratic response in milk fat yield (Table 4; Figure 2), despite milk volume being greatest at 65% concentrate. Maximum fat yield was estimated to occur at 38% NFC (about 54% AS) in the diet. Changes in the pattern of ruminal fermentation, including increased propionate and reduced acetate, acetate:propionate ratio, and pH that occurred in this trial (32), likely reflected the lower fiber digestibility (Table 3) plus the lower fiber intake (Table 5) occurring when cows were fed the most concentrate. For example, NDF apparently digested in the total tract (Tables 3 and 5) was computed to be 3.5 and 2.5 kg/d, respectively, in cows fed 20 and 65% concentrate. Ruminal NDF fermentation will influence acetate supply to the cow because greater proportions of carbohydrate in cellulose and hemicellulose than starch are fermented to acetate (20).

One of the principal objectives of this research was todetermine the effectiveness of feeding high amounts of concentrate to stimulate utilization of dietary CP, 43% of which was from NPN. Milk content and yield of protein, lactose, and SNF all responded linearly (Table 6; Figure 2) as AS was replaced with increasing amounts of dietary concentrate, supplying more NFC. The pattern of mean separation for yield of protein, lactose, and SNF was identical: lowest with 20%, intermediate with 35 and 50%, and greatest with 65% concentrate. Protein plus lactose account for nearly all of milk SNF yield and, thus, respond similarly (Figure 2): increasing dietary concentrate from 20 to 65%, increased milk protein, lactose, and SNF content by 0.2, 0.1, and 0.3 percentage units, respectively (Table 6). Sutton (30) summarized data indicating that increasing fermentable energy, by reducing dietary forage to concentrate ratio, and increasing RUP intake, elevated milk contents of protein, lactose, and SNF. Increasing microbial protein synthesis with greater NFC intake would be expected to increase amino acid supply for

Table 6. Effect of replacing dietary alfalfa silage with concentrate on yield of milk and milk components and milk/DMI.[1]

Item	Dietary concentrate (% of DM)				SE	P<	
	20	35	50	65		L	Q
Milk, kg/d	31.2[d]	36.0[c]	39.8[b]	43.4[a]	0.6	0.002	0.338
Milk/DM intake	1.41[b]	1.42[b]	1.50[b]	1.71[a]	0.03	0.069	0.005
3.5% FCM, kg/d	32.4[c]	37.7[b]	41.6[a]	40.8[a]	0.8	<0.001	<0.001
Fat, %	3.77[a]	3.83[a]	3.77[a]	3.16[b]	0.09	<0.001	<0.001
Fat, kg/d	1.32[b]	1.43[ab]	1.49[a]	1.32[b]	0.04	0.001	0.001
Protein, %	2.85[c]	2.94[bc]	3.01[ab]	3.06[a]	0.03	<0.001	0.516
Protein, kg/d	1.01[c]	1.09[bc]	1.19[ab]	1.28[a]	0.03	<0.001	0.982
Lactose, %	4.76[b]	4.81[ab]	4.87[a]	4.86[a]	0.02	0.002	0.223
Lactose, kg/d	1.69[c]	1.81[bc]	1.93[ab]	2.05[a]	0.04	<0.001	0.972
SNF, %	8.37[c]	8.51[bc]	8.64[ab]	8.68[a]	0.04	<0.001	0.216
SNF, kg/d	2.96[c]	3.19[bc]	3.41[ab]	3.64[a]	0.07	<0.001	0.998
MUN, mg/dl	25.0[ab]	25.7[a]	24.0[b]	20.6[c]	0.4	0.134	0.033
MUN, % of total N	4.85[ab]	5.26[a]	5.07[a]	4.41[b]	0.16	0.164	0.074
MUN, g/d	7.75[b]	9.27[a]	9.46[a]	8.78[a]	0.20	0.007	0.023

[a,b,c,d]Means in rows with different superscripts differ ($P < 0.05$).

[1]L = Linear effect, Q = quadratic effect, MUN = milk urea N.

milk protein synthesis. Diets containing 35 to 65% concentrate also were supplemented with increasing amounts of SBM in this trial. Although its ruminal escape is estimated at only 35% (21), CP from SBM likely contributes more absorbable protein than does comparable amounts of CP from AS (2). Extensive gluconeogenesis is necessary to produce the large amounts of glucose required for lactose synthesis; this is a major fate of absorbed amino acids in lactating cows (9). Increased ruminal propionate formation that occurred with increased dietary NFC in this trial (32) would be expected to increase the supply of that major gluconeogenic substrate and, thus, spare amino acids from catabolism for lactose synthesis (9). Concentrations of MUN were typical for cows fed very high dietary total CP and NPN (Table 1). Computing MUN with a regression equation relating CP with MUN (3) indicated that 19.8% dietary P would give rise to 22.7 mg of MUN/dl; mean trial MUN was 23.8 mg/dl. The lowest MUN concentrations and proportions of total milk N were observed in cows fed 65% dietary concentrate (Table 6), also reflecting improved ruminal utilization of RDP and recycled urea. Secretion of MUN was estimated to be maximal at 37% dietary NFC (Table 4), which corresponded to about 51% dietary concentrate. Probably because milk volume was lowest at 20% concentrate, the lowest quantity of MUN was secreted on that diet (Table 6). In the present trial, MUN concentration was an effective indicator of CP utilization (3).

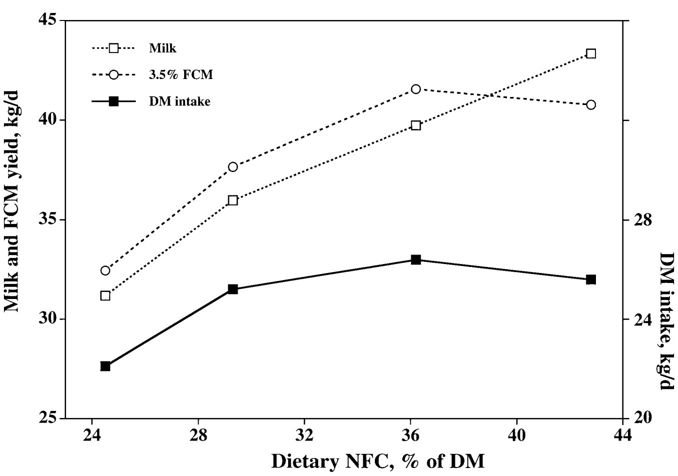

Figure 1. Mean daily yields of milk (❐) and 3.5% FCM (○) and DMI (■) over the last 2 wk of the 3-wk period for cows fed diets with (DM basis) 80, 65, 50, and 35% alfalfa silage corresponding to, respectively, 24, 29, 36, and 43% nonfiber carbohydrate (NFC).

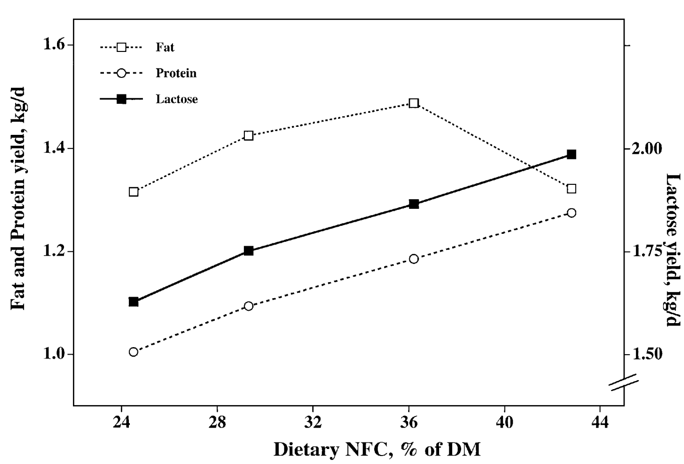

Figure 2. Mean daily yields of fat (❐), protein (○), and lactose (■) over the last two wk of the 3-wk period for cows fed diets with (DM basis) 80, 65, 50, and 35% alfalfa silage corresponding to, respectively, 24, 29, 36, and 43% nonfiber carbohydrate (NFC).

Energy requirements for the cows in this trial were computed from animal performance as the sum of energy required for maintenance (BW = 630 kg), BW change (gain or loss), and yield of 3.5% FCM (21). Requirements for NE_L obtained in this way were: 31.6, 39.3, 41.7, and 38.8 Mcal/d for the cows fed the diets containing 20, 35, 50, and 65% concentrate. Dividing these NE_L requirements by DMI yielded NE_L estimates for the four diets of 1.43, 1.56, 1.58, and 1.52 Mcal/kg of DM, suggesting a decline in energy value at the highest level of dietary concentrate. The NE_L content can be computed from apparent digestibilities observed in this trial, assuming DOM was equivalent to TDN: NE_L (Mcal/kg of DM) = 0.0245 DOM − 0.12 (18). Values of 1.23, 1.34, 1.41, and 1.54 Mcal NE_L/kg of DM were computed for diets containing 20, 35, 50, and 65% concentrate. These latter estimates averaged only 86% of the NE_L computed from NRC (21) tables for the four diets (Table 1); there also was poor agreement between NE_L estimates made from DOM and those computed from animal performance. The NE_L values computed by assuming apparent OM digestibility was equivalent to TDN (18) appeared not to be accurate due to an underestimation of digestibility using indigestible ADF as the internal marker.

CONCLUSIONS

Results indicated that a 7-d adaptation period was adequate for lactating cows used in a 4 × 4 Latin square feeding trial with 21-d periods. There were quadratic responses in performance when HMEC-based concentrate replaced AS in cows fed AS as the only forage. Fiber (NDF and ADF) intake was maximal at 25 to 27% dietary NFC. Maximal fat yield occurred at 34% dietary NFC, while maximal DMI and yield of FCM occurred at 37 and 38% dietary NFC, respectively. However, yields of milk, protein, lactose, and SNF were not yet maximal at 65% concentrate (43% NFC), the highest level of dietary concentrate. Increasing intake of NFC increased utilization of dietary CP and NPN and yields of milk and non-fat milk components in this short-term trial.

ACKNOWLEDGMENTS

The authors thank Len Strozinski and the barn crew at the US Dairy Forage Center Research Farm (Prairie du Sac, WI) for assistance in animal care and sampling; Brad Ricker, Mary Becker, Becky Sannes, Eduardo Vargas, and Mehmet Bal for assisting with laboratory analyses; and Peter Crump for assisting with statistical analyses.

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